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INTEGRAL COLOR ANODIZING OF ALUMINUM ALLOY 7075-T6 UPPER RECEIVERS OF THE M16A1 RIFLE

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U.S. ARMY MOBILITY EQUIPMENT
RESEARCH AND DEVELOPMENT COMMAND
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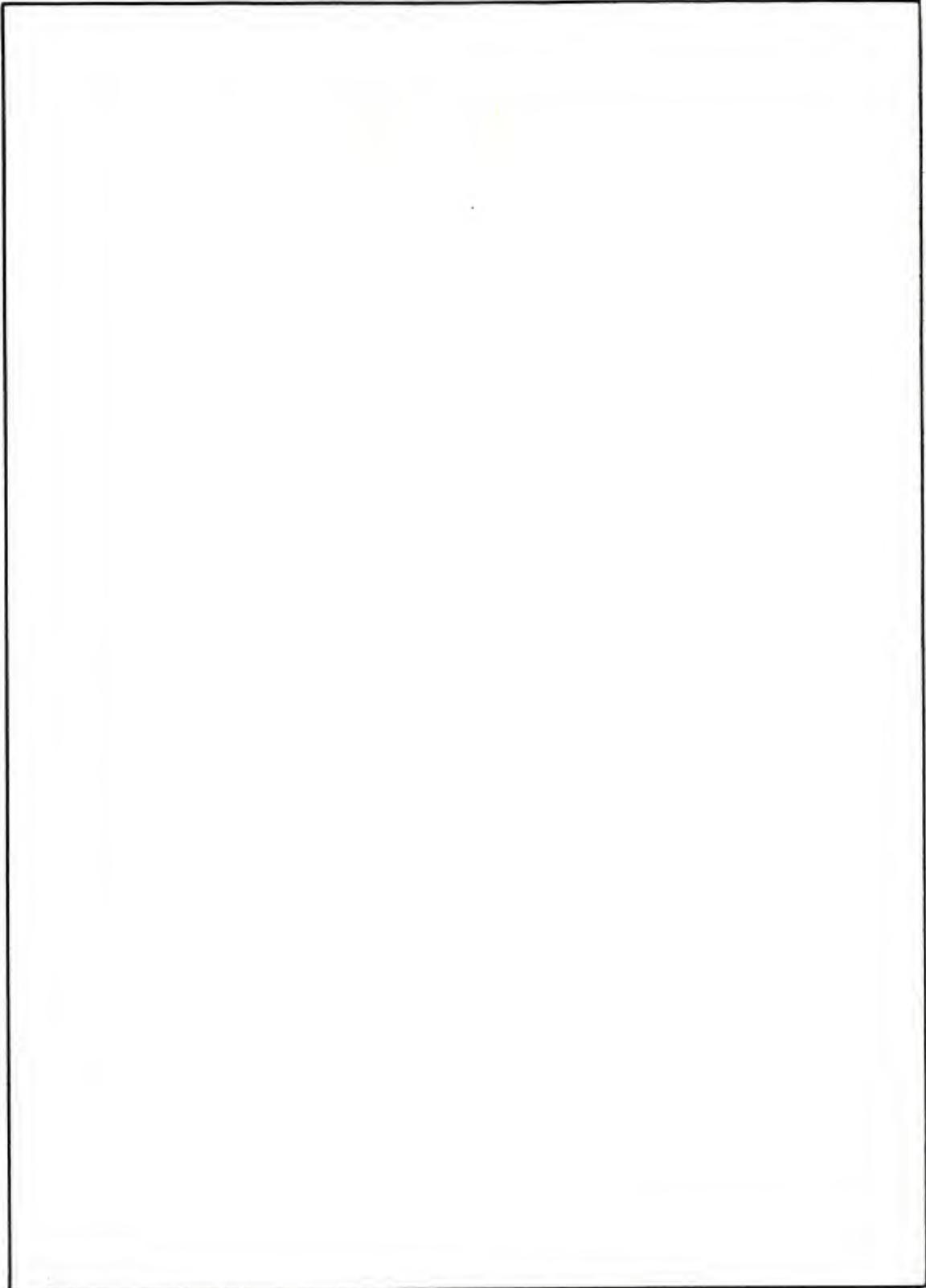
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INTEGRAL COLOR ANODIZING OF ALUMINUM ALLOY 7075-T6

UPPER RECEIVERS OF THE M16A1 RIFLE

I. INTRODUCTION

1. Statement of the Problem. The investigation was undertaken to provide a commercially available integral color anodizing (ICA) production process for hard coating aluminum alloy 7075-T6 upper and lower receivers for the M16A1 rifle.

2. Background. The aluminum alloy 7075-T6 upper and lower receivers for the M16A1 rifle are generally hard anodized (coated) by a conventional low-temperature (32° to 40° F) sulfuric acid process (MIL-A-8625, Type III). The treated parts are then dyed black in a separate processing tank. The dyeing process utilizes the absorption of organic dyestuffs or precipitation of various insoluble metal compounds into the pores of the anodic coating. Such color systems applied to weapon components may be susceptible to thermal and environmental decomposition under usual service conditions. In addition, the low-temperature hardcoat, because of its formation at low temperatures (32° to 40° F), tends to form fine cracks in the oxide coatings.¹ The cracks, which are formed because of the difference in thermal expansion between the oxide layer and the aluminum substrate, have been shown to be potential corrosion sites in some instances.² Improvement in the overall quality of the hardcoat and economy of its production could be expected by employing integral color anodizing, a room temperature process. This term applies to those processes in which the developed color is a function of the particular alloy and anodizing treatment in organic acid electrolyte such as sulfophthalic or sulfosalicylic acids plus various amounts of sulfuric acid.³ The organic acids act to inhibit the acid attack on the developing oxide coating thus permitting the formation of thick layers with excellent abrasion resistance which are normally referred to as "hard coat."

II. EXPERIMENTAL PROCEDURE

3. Approach to the Problem. The task directive (ARRADCOM letter of 4 August 1978) consisted of the following:

a. Survey of commercially available integral color anodizing processes for application to aluminum alloy 7075-T6.

¹ S. Wernick and R. Pinner, "The Surface Treatment and Finishing of Aluminum and Its Alloys," 3rd Edition, Robert Draper, LTD., 1964.

² S. Levine, "A Scanning Electron Microscopic Study of Corner Defect in Hard Anodized Aluminum," *Plating and Surface Finishing*, Dec 76.

³ *Metal Finishing Guidebook Directory*, Metals and Plastic Publication, p. 552, 1971.

b. Evaluation of candidate coatings relative to coating thickness, color and thermal stability, abrasion (wear) and corrosion resistance, and discontinuity sites (potential corrosion sites.)

c. Application of the most feasible treatment to actual receivers.

4. Processes Selected for Consideration. Although it was soon evident that the open literature (patent literature as well) abounds in ambient-temperature hard coating techniques, it appeared, from the requirements of this project, that only commercially available ICA processes should be considered. Three well known ICA processes — Kalcolor (Kaiser Aluminum and Chemical Company); Duranodic (Aluminum Company of America); and Reynocolor, later called Multipurpose Anodizing Electrolyte (MAE) (Reynolds Aluminum Company) — were selected as the processes to be studied for this project.

Target alloy 7075-T6 coupons, center-punched to provide access to a Taber Abraser, were prepared. Coupons were sent to 12 firms that appeared to have the capability of applying their form of an ICA hardcoat. The treated coupons, representing commercially available ICA and conventional low-temperature hardcoat processes, were characterized in-house as to color and heat stability; abrasion and corrosion resistance; coating thickness and porosity (discontinuities). Characterization of the coatings produced by these processes was accomplished in two phases. Cooperating firms were requested only to supply ICA-treated 7075-T6 coupons that had a 0.002-inch \pm 0.0002-inch thick coating and were black in color. The submitted treated coupons were examined for color and coating thickness as a preliminary characterization; those coupons that were unacceptable were eliminated from any further consideration in this study; acceptably treated coupons were then subjected to further evaluation.

5. Results. Six of the 12 firms that were contacted relative to submitting ICA treated 7075-T6 coupons for our evaluation responded with interest. Of those 6 firms, 3 submitted Kalcolor processed coupons, 3 submitted Duranodic processed coupons, and 1 submitted MAE processed coupons. The Kalcolor processed coupons were unacceptable with respect to coating thickness, color, and uniformity of color and were dropped from further consideration. The Duranodic processed coupons obtained from two vendors appeared to have the greatest potential. Conventional hardcoat treated and dyed coupons, received from some vendors, were characterized along with the ICA coupons for comparison purposes.

Characterization tests and observations of treated coupons were as follows:

a. **Corrosion Resistance, 500 Hours Salt Fog:**

- (1) Lustrik, Inc. – Duranodic (ICA), 1.6 mils thick (several small corrosion sites).
- (2) Lustrik, Inc. – Hardcoat, low-temperature, 2.6 mils (several small corrosion sites).
- (3) Duralectric – Sanford Hardcoat, low-temperature, 2 mils (several small pits).
- (4) Hytek (originally Heath-Tecna Company) – Duranodic (ICA), 1.1 mils (numerous superficial pits, 2 or 3 white corrosion product areas).

b. **Light Fastness, Xenon Weatherometer Plus Water 200 Hours:**

- (1) Lustrik, Inc. – Duranodic (ICA), gray 1.6 mils (no change in color).
- (2) Duralectric – Sanford Hardcoat, low-temperature, dyed black, 2 mils (no change in color).
- (3) Hytek – Duranodic (ICA), blue-black, 1.1 mils (no change in color).
- (4) Hytek – Duranodic (ICA), charcoal-gray, 1.5 mils (no change in color).

c. **Table Abrasion Resistance, 10,000 Cycles, CS17 Abrasion Test Wheels and 1000-gram Load:**

	Loss, grams
(1) Duralectric – Sanford Hardcoat, dyed black, low-temperature, 2.0 mils (hot water sealed).	0.0185
(2) Lustrik, Inc. – Hardcoat, low-temperature, 2.6 mils.	0.0128
(3) Hytek – Duranodic (ICA), blue-black, 1.1 mils.	0.0089
(4) Hytek – Duranodic (ICA), blue-gray, 1.7 mils.	0.0067

(5) Hytek – Duranodic (ICA), charcoal-gray, 1.5 mils. 0.0180
(hot water sealed).

(6) Reynolds – MAE (ICA), 2.3 mils. 0.0087

d. Taber Abrasion Resistance, 10,000 Cycles, CS17 Abrasion Test Wheels, 1000-gram Load (Heated 325° F):

(1) Duralectric (ICA) – Sanford Hardcoat, dyed black, 0.0077
low-temperature, 2.2 mils (heated 56½ hours).

(2) Hytek – Duranodic (ICA), blue-gray, 1.75 mils 0.0065
(heated 76½ hours).

(3) Hytek – Duranodic (ICA), blue-gray, 1.70 mils 0.0076
(heated 56½ hours).

(4) Hytek – Duranodic (ICA), blue-gray, 1.60 mils 0.0051
(heated 56½ hours).

(5) Hytek – Duranodic (ICA), charcoal gray, 1.5 mils 0.0107
(heated 24 hours).

(6) Reynolds – MAE (ICA), 2.2 mils (heated 1 hour; 0.0086
cooled in furnace).

(7) Reynolds – MAE (ICA), 2.3 mils (heated 31 hours; 0.0106
cooled in furnace).

e. Porosity^{4 5} (Film Continuity) Test – As-received:

(1) Duralectric – Sanford Hardcoat, dyed black, 2.2 mils (heavy population⁶) (Figure 1a).

(2) Hytek – Duranodic ICA, blue-gray, 1.75 mils (nil population)
(Figure 2a).

⁴ Crystalline CuSO₄ – 20g; Hydrochloric acid – 20 ml; Water to 1 liter; Use 2 drops, after 20 minutes, remove acid by gentle movement in distilled water and observe for copper metal sites, indicating a discontinuity.

⁵ "Anodic Oxidation of Aluminum and Its Alloys," Information Bulletin No. 14, The Aluminum Development Association, p. 119, London, 1961.

⁶ Density of the metallic copper specks on the test site (visual inspection); the heavier the density (population), the greater the porosity.

- (3) Hytek - Duranodic ICA, blue-gray, 1.6 mils (nil population).
 - (4) Hytek - Duranodic ICA, charcoal gray, 1.5 mils (nil population).
 - (5) Hytek - Duranodic ICA, black, 1.1 mils (light population). This coupon had been in weatherometer for 168 hours.
 - (6) Lustrik - Duranodic (ICA), 1.6 mils (light population).
 - (7) Lustrik - low-temperature hardcoat, 2.6 mils (moderate population) (Figure 3a).
 - (8) Reynolds - MAE ICA, 2.3 mils (light population) (Figure 4a).
- f. **Porosity (Film Continuity) Test - Heated Coupons:**
- (1) Duralectric - Sanford Hardcoat, dyed black, 2.2 mils (heavy population) (Figure 1b).
 - (2) Hytek - Duranodic (ICA), blue-gray, 1.75 mils, heated 76½ hours (almost nil population) (Figure 2b).
 - (3) Hytek - Duranodic (ICA), blue-gray, 1.6 mils, heated 56½ hours (light population).
 - (4) Hytek - Duranodic (ICA), charcoal-gray, 1.6 mils, heated 24 hours (moderate population).
 - (5) Lustrik - Duranodic (ICA), 1.6 mils, heated 56½ hours (heavy population).
 - (6) Lustrik - low-temperature hardcoat, 2.6 mils (heavy population) (Figure 3b).
 - (7) Reynolds - MAE (ICA), 2.7 mils, heated 31 hours (heavy population) (Figure 4b).

g. **Craze or Crack Pattern at 325° F (Viewed at 30X Magnification):**

- (1) Duralectric - Sanford Hardcoat, dyed black, 2.2 mils, heated 56½ hours (no cracks).

(2) Reynolds Aluminum — MAE (ICA), 2.3 mils, heated 56½ hours (crack pattern) (note clearly defined crack patterns in Figure 4b).

(3) Reynolds Aluminum — MAE (ICA), 2.2 mils, heated 4½ hours (crack pattern; cooled in furnace prior to observation).

(4) Reynolds Aluminum — MAE (ICA), 2.3 mils, heated one hour (crack pattern; cooled in furnace prior to observation).

(5) Lustrik — Duranodic (ICA), 1.6 mils, heated 56½ hours (crack pattern; this coupon had previously been exposed to Xenon weatherometer for 168 hours).

(6) Hytek — Duranodic (ICA), blue-gray, 1.6 mils, heated 56½ hours (no cracks).

(7) Hytek — Duranodic (ICA), blue-gray, 1.7 mils, heated 56½ hours (no cracks).

(8) Hytek — Duranodic (ICA), blue-gray, 1.8 mils, heated 76½ hours (no cracks).

(9) Hytek — Duranodic (ICA), charcoal gray, 1.5 mils, water sealed, heated 24 hours (faint crack pattern).

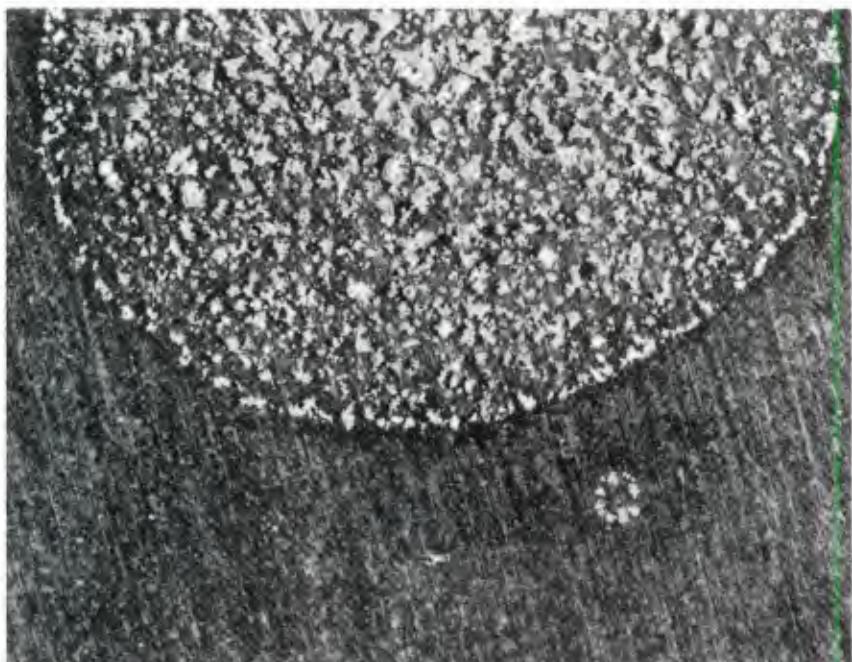
Coupons were evaluated at 325° F so as to simulate the thermal effect upon a weapon that has been subjected to a prolonged period of rapid firing. Specimens that formed easily visible crack or craze patterns upon heating actually formed these patterns within an hour of being subjected to the 325° F temperature. These easily cracked specimens formed the crack patterns even when subjected to a gradual rise and/or decrease in temperature as shown in Figure 4b.

III. DISCUSSION

6. Discussion. Integral Color Anodizing (ICA) originally developed as an architectural process, appears to be in an active development state at present. Although there are other ICA processes that may be explored; the three processes investigated in this project — Kalcolor, Duranodic and Reynocolor (Multipurpose Anodizing Electrolyte) — appeared to be the most commonly used and commercially available ICA treatments for aluminum and thus were selected for this program. In general, many of the vendors contacted expressed some reluctance to treat 7075, especially to obtain a black finish. It was also discovered that although the vendors are



a



b

Figure 1. Duraelectric Sanford Hardcoat, dyed black, 2.2 mils — Porosity Test 9X:

- a. Not heated.
- b. Heated 56½ hours, 315° F.



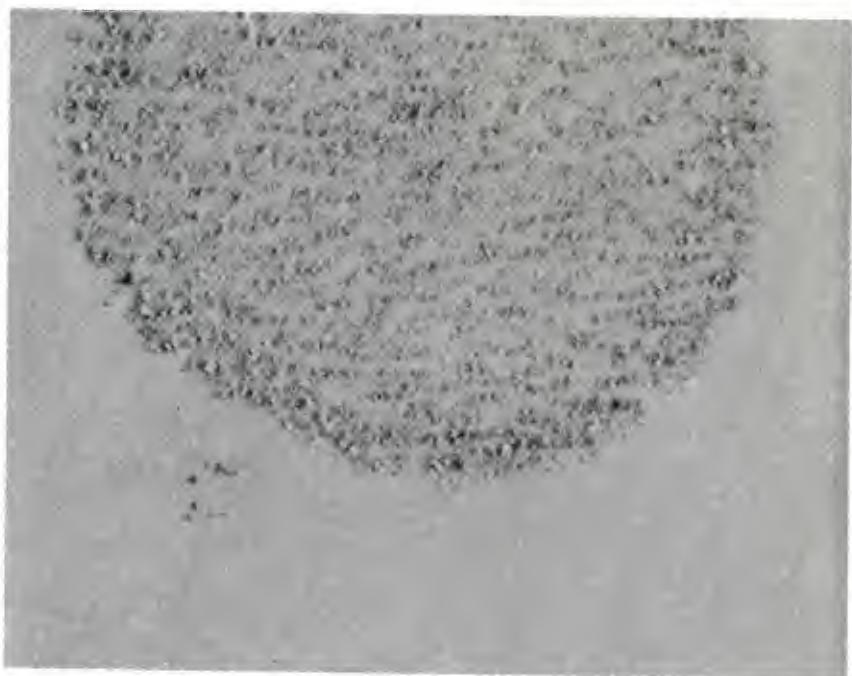
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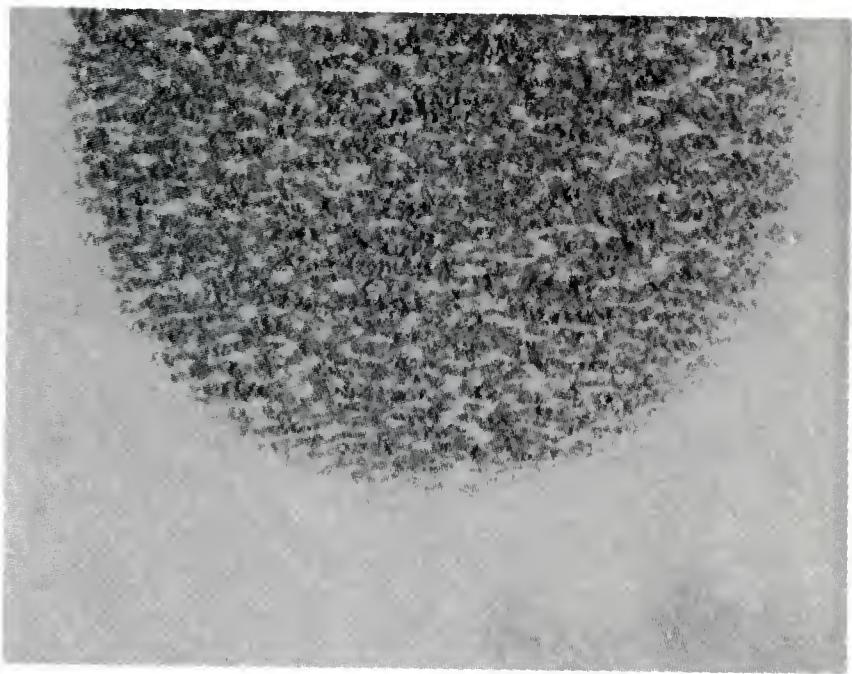
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Figure 2. Hytek, Duranodic ICA, 1.75 mils — Porosity Test 9X:

- a. Not heated.
- b. Heated 76½ hours, 325° F.



a



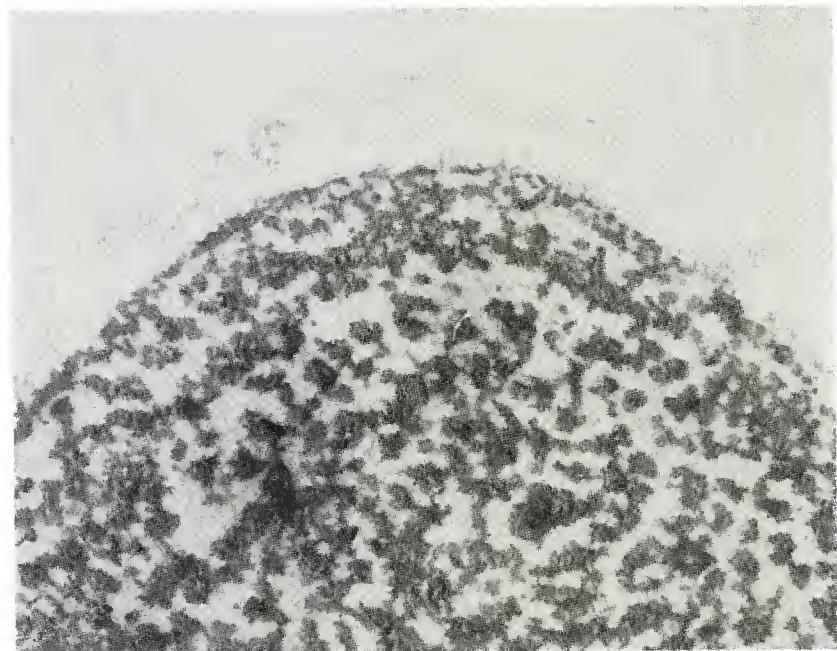
b

Figure 3. Lustrik, Low-Temperature Hardcoat, 2.6 mils – Porosity Test 9X:

- a. Not heated.
- b. Heated 56½ hours, 325° F.



a



b

Figure 4. Reynolds, MAE ICA, 2.3 mils — Porosity Test 9X:

- a. Not heated.
- b. Heated 56½ hours, 325° F.

licensees of a particular patent holder, they had their own versions of that particular ICA process. The Duranodic process, for example, an Aluminum Company of America (ALCOA) process, was utilized by at least three of the vendors that submitted treated coupons. These coupons, from different vendors, using the Duranodic process, varied in color, appearance, and coating thickness although the same coating requirements had been cited in the original letter of inquiry. It was noted that the difficulty in obtaining a black finish, increased with increasing thickness. This was demonstrated with coupons (furnished by Hytek Finishes Company) that were an acceptable black at 1.1 mils thick and then became blue-gray in color at 1.7 mils. With some manipulations of the electrical parameters, this company finally succeeded in obtaining an acceptable black, actually a charcoal gray color that conformed to Military Standard No. 595, lusterless 36076.

7. **Field Test.** When it appeared evident that integral color anodizing, actually known as an architectural process, could provide suitable dark (no dye) hardcoat finish for aluminum alloy 7076-T6, it became necessary to determine applicability to actual receiver parts (aluminum alloy 7075-T6 forgings). This was accomplished during a visit to the Hytek metal finishing facility. Several new and several stripped upper receivers were treated successfully with the Hytek version of the Duranodic ICA hard coating process. During this stage of the development, it was also learned that a pre-ICA shot-peening treatment produced an even charcoal-gray colored surface. Thus, the upper receivers of the M16A1 rifle treated with the Hytek version of the Duranodic ICA process now appeared to be ready for the final test phase of this project, namely a field trial.

A design test plan was submitted by the US Army Infantry Board (USA IB Project No. 3688) for a comparative field evaluation of the wear and corrosion and heat resistance characteristics of the M16A1 rifle upper receiver treated with the above ICA coating and with the treated upper receiver currently used on the M16A1 rifle. The test design required 30 each, test and new control upper receivers to be assembled to M16A1 rifles. The rifles with test and control upper receivers were carried, fired, and maintained by soldiers in the field undergoing basic and advanced Infantry training and by other soldiers undergoing Ranger training. The test and control items were subjected to typical field usage conditions involving rough handling, firing, and soldier maintenance under prevailing conditions during a 3-month period between September and December 1980. After completion of the 3-month test period, the test and control receivers were taken off the rifles and inspected for wear and corrosion. A final report⁷ and an additional examination of the test and standard upper receivers by ARRADCOM engineering personnel, with many years of experience with the M16A1 rifle indicated that the test hardcoat process appeared to provide a greater degree of protection than did the standard hardcoat (see the Appendix).

⁷ "Field Test of Prototype Upper Receiver (Experimental Hardcoat Process) for M16A1 Rifle," USAIFB Report, Feb 81.

8. **Economics.** The comparative unit cost of treating the aluminum alloy 7075-T6 receivers with ICA or low-temperature hardcoat has not been explored fully. However, it is expected that ICA, a room-temperature and dyeless process, will be less costly to apply than the low-temperature hardcoat dyed finish used currently. Hytek Finishes Company estimated that the unit cost of processing 500 units, in a like manner to those provided for the above described field test, would be \$1.85 each compared to \$2.75 for the conventional low-temperature hardcoated and dyed finish.

IV. CONCLUSIONS

9. **Conclusions.** It is concluded that:

a. The anodizing process for aluminum, known as Integral Color Anodizing (ICA), is capable of providing aluminum alloy 7075-T6 upper receivers for the M16A1 rifle, with a superior wear- and corrosion-resistant finish.

b. The unit cost for application of ICA to the aluminum alloy 7075-T6 upper receivers for the M16A1 rifle is substantially lower than that of the coating produced by conventional low-temperature hard anodizing.

c. The above conclusions are also applicable to the aluminum alloy 7075-T6 lower receivers for the M16A1 rifle.

d. It is likely that the overall superiority of the ICA hardcoat treatment will provide a longer inservice life for the M16A1 rifle receivers than will the low-temperature hardcoat process.

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APPENDIX

The test and control M16 upper receivers were examined by engineering personnel with many years of experience on the M16 rifle. Only subjective comments are possible on the basis of this examination.

It is the opinion of all of the engineering personnel involved that the test hardcoat process appears to be distinctly better from the standpoint of wear due to normal handling operations. There appears to be significantly fewer surface scratches or "bright metal" defects on the test receivers as compared with the control receivers. There are no obvious or identifiable disadvantages of the test process.

If, as we understand it, the test process coated receivers fared better in the various adverse environmental engineering tests, it would appear highly desirable in future small caliber weapon applications.

It is requested that we be provided with your recommended drawing call-outs for specifying this finish on a trial basis in current RDT&E weapon prototyping projects.

* Received from Charles J. Rhoades, Chief, Small Caliber Weapons Branch, Armament Div, FC&SCWSL, US Armament Research and Development Command.

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